

****Volume Title****

*ASP Conference Series, Vol. **Volume Number***

****Author****

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Nearby Motionless Stars

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Abstract.

We present methods and preliminary results of a relatively novel search for nearby stars. The method relies on photometric distance estimates as its primary search criterion, thus distinguishing itself from proper motion-based searches that have produced the bulk of nearby star discoveries.

1. History of nearby star discoveries

Over the last 200 years, proper motion (the apparent motion of stars across the sky, seen over periods of years) has been used to find nearby stars. This approach has been based on the idea that stars move through space, and the closest ones should appear to move the fastest. Currently, we understand that this is due to the combination of the motions of the Sun and the star in question in their orbits around the center of the Galaxy, though this idea predates the discovery of the Galaxy and our place in it by at least 150 years. The earliest reference available seems to be William Herschel (Herschel 1783), who claims the phenomena is well-established and credits its discovery to Sir Edmund Halley.

This property of large proper motion has served nearby star research well from the very beginning, forming at least part of the decisions of Bessel (1838) and Henderson (1839) to observe 61 Cygni and Alpha Centauri (respectively) for parallax. The trend continues to the present. Nearly all nearby stars known have high proper motions, with the limit of high proper motion ($0.5''\text{yr}^{-1}$, van Maanen) or interesting proper motion ($0.2''\text{yr}^{-1}$, the Royal Greenwich Observatory) set by influential publications in the early part of the 20th century (Luyten 1988). Though Luyten does not give the reasoning

behind either argument, we suspect the $0.2''\text{yr}^{-1}$ limit was likely the best that could be done visually with the photographic plates and blink comparators of the time.

Still, there are signs proper motion is not an entirely foolproof method. Proxima Centauri, the closest star to Earth, is only the 18th highest proper motion star in the New Luyten Two Tenths Catalog (Luyten 1979b, , though the other 17 are also very nearby stars) (though the other 17 are also very nearby stars). By the same token, many brighter stars were singled out for parallax, e.g. Hipparcos observed all stars brighter than $V=7.3$ (Perryman et al. 1997) and discovered not all objects within 25 parsecs are fast moving. One good example is Gl 566, which despite a distance of 6.7 parsecs is moving at $0.169''\text{yr}^{-1}$. It would likely not have been noticed except that it is a 5th magnitude G star with a K companion and visible orbital motion.

In any case, years later we still have unfinished business. The situation is currently thus: assuming that 50 parallax-verified systems within 5 parsecs is a statistically meaningful sample, there should be 400 stars within 10 parsecs (8 times the volume), and 6250 systems within 25 parsecs (125 times the volume). The current tally is 256 parallax-verified systems within 10 parsecs¹ and 2011 parallax-verified systems within 25 parsecs (NStars, Henry et al. 2002). We are missing nearly 36% of systems within 10 pc and 68% of all stars within 25 pc.

2. Where are the stars?

The most obvious reason stars are missing is that we simply do not have accurate trigonometric parallaxes for all potential nearby stars we know of. The Luyten Half Second catalog (2nd ed) (Luyten 1979a), New Luyten Two Tenths catalog (Luyten 1979b), and Giclas survey papers (final entries, Giclas et al. 1979) contain the most complete samples of potentially nearby proper motion objects with over 50,000 stars, and were published three decades ago. We still have no reliable trigonometric parallax for large numbers of these high-proper-motion systems (e.g. Riedel et al. 2010), particularly the ones fainter than the completeness limit of Hipparcos. This is an area where existing parallax programs and future programs like LSST, URAT, Skymapper, PanSTARRS and Gaia will have a huge impact.

There are still, however, many nearby stars we have not identified yet. They fall into three basic groups:

Stars simply missed by Luyten and Giclas. Luyten's NLTT survey was done with hand-blinked plates in the far south from his earlier BPM survey (which had a limiting magnitude of $R=16.5$) and machine-scanned plates from the Luyten-Palomar survey ($R=19$) for northern regions, with a limit of $\mu > 0.18''\text{yr}^{-1}$ to make certain he found all stars moving faster than $0.20''\text{yr}^{-1}$. Giclas' Lowell Proper Motion survey ($R=16.5$) had a nominal limit of $0.27''\text{yr}^{-1}$ and a goal of finding every object moving faster than $0.30''\text{yr}^{-1}$; that proper motion limit was later reduced to $0.20''\text{yr}^{-1}$ in the southern hemisphere, but the survey was left unfinished in 1979. Lépine & Shara (2005) estimate Luyten's ~90% completion limit to be $V=15$ within 10 degrees of the galactic plane, and $V=18$ elsewhere. Many astronomers (too numerous to note) have had successful programs locating such objects, particularly in the south, where Giclas was unfinished and Luyten hand-blinked plates with brighter limiting magnitudes.

¹RECONS 10 pc census, <http://www.recons.org/census.posted.htm>; Henry, T.J. accessed 2010-12-01

Stars too faint to be seen by Luyten or Giclas. Luyten and Giclas were both limited by the sensitivity and waveband of their first or second epoch plates. The smallest stars (M9.5V or L0V) have absolute magnitudes of $R=18$, therefore the Luyten and Giclas surveys cannot complete a nearby star sample out to a distance of 25 pc (distance modulus ~ 2), where such stars are roughly $R=20$. Surveys with fainter magnitude limits (including those that scan photographic plates to lower magnitude limits) and that use infrared wavebands are better suited to detect faint nearby stars.

Stars moving too slowly for Luyten or Giclas. The limits set by Luyten (and the Royal Greenwich Observatory before him) were more out of necessity than scientific reason; going to smaller motions releases a flood of new objects that are much harder to measure accurately. With the development of modern computing capabilities, though, such things become possible. Many recent surveys have breached the $0.18''\text{yr}^{-1}$ limit, although none have explicitly surveyed tiny proper motion objects.

3. A different method for finding nearby stars: TINYMO

We have chosen to focus our survey on finding extremely low proper motion objects, rather than fainter stars. Space velocity dispersions calculated from known nearby stars (themselves potentially biased toward high transverse velocities) can be used in Monte Carlo simulations of nearby stars; one such simulation is shown in Figure 1, where the distribution of stars within 25 pc is modeled based on the velocity dispersions in Aumer & Binney (2009) and color/number distributions from RECONS², assuming an actual population of 6250 systems. As is visible in the figure, while most systems are moving faster than $0.18''\text{yr}^{-1}$, a sizable portion (14.6% in this simulation) are moving more slowly; only 31% of those are currently known. These undiscovered systems may be quite bright and easy to study with current instrumentation.

The TINYMO survey is designed to detect these slow-moving nearby stars using photometric distance estimates as the primary selection criterion, avoiding (except for a rough upper limit) proper motions entirely. It thus avoids many of the pitfalls of using proper motion to search for truly zero proper motion³ nearby stars, most notably a.) there is a finite limit to how well proper motions may be measured from any given source, and b.) even distant background objects are moving at some level.

The so-called TINYMO search for essentially non-moving stars was conducted (much like previous RECONS searches in Subasavage et al. (2005) and Finch et al. (2007)) using the SuperCOSMOS Sky Survey (Hambly et al. 2001) to search for tiny proper motion stars in the southern hemisphere, among the ~ 1 billion distinct catalog entries. The empirical SuperCOSMOS $B_J R_2 I$ and 2MASS JHK_s plate photometry relations in (Hambly et al. 2004) were used to obtain distance estimates to these targets, with the intent to select stars within 25 pc.

Spatially, TINYMO (currently) only contains stars in the southern hemisphere, more than 10 degrees from the galactic plane and more than 20 degrees from the galactic bulge. This time, we required targets to be detected on all four (B_J , R_1 , R_2 ,

²<http://www.recons.org/census.posted.htm>; Henry, T.J. accessed 2010-12-01

³Interestingly, there is also a problem with detecting high proper motion objects, which Henry et al. (2004) and Lépine et al. (2005) prove are still missing; for the most part the problem is identifying widely separated “single” hits as an individual moving star, rather than plate defects or transient sources

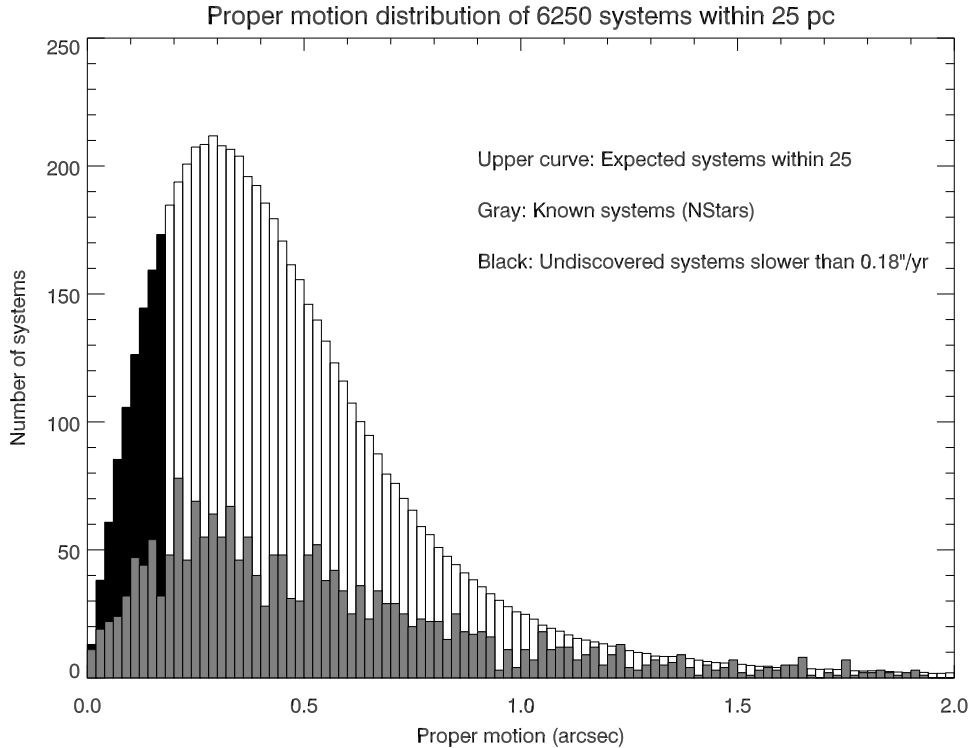


Figure 1. A Monte-Carlo simulation of stars within 25 pc of the Sun (black/white) using velocity dispersions from Aumer & Binney (2009); known objects (gray) are from the NStars 25 pc database (Henry et al. 2002)

I^4) plates (which effectively required all four detections to be within $6''$ of each other, Hambly et al. 2001) and with a 2MASS detection within $5''$ of the weighted mean plate position. While that is technically a proper motion limit, it is an *upper* limit, dependent on the epoch spread of individual plates; it is merely included to enforce the selection of only the slow-moving objects we wish to study.

The nearly 14 million resulting non-moving objects were then run through the SuperCOSMOS $B_J R_2 I$ and 2MASS JHK_s main-sequence photometric color relations from Hambly et al. (2004); less than 89000 objects were estimated to be within 25 pc.

Finally, a color-color criterion in $J-K_s$ vs $\nu-K$ colorspace (the average of SuperCOSMOS B_J and R_2 is taken as our simulated ν) was applied, with the goal of separating main sequence objects from giants. The color-selection boxes can be seen in Figure 2, plotted in $\nu-K_s$ vs $J-K_s$ space. A decision was made early on to keep targets in boxes 2 and 3 (brown dwarf colors), even though they are severely contaminated by giants.

At this stage, the 1154 remaining color-selected objects were blinked using SuperCOSMOS plates and Aladin's SIMBAD overlay loaded into the Aladin Skyview Applet, and individually examined to check if they were a.) real objects, b.) moving (if possible), c.) matched to the proper 2MASS point (mistakes in the 2MASS identi-

⁴ B_J is the Science and Engineering Research Council (SERC)-J survey; R_1 is POSS-I E between 0 DEC and -18 DEC and ESO-R below -20 DEC; R_2 is SERC-ER_{59F}, and I is SERC-I_{1VN}

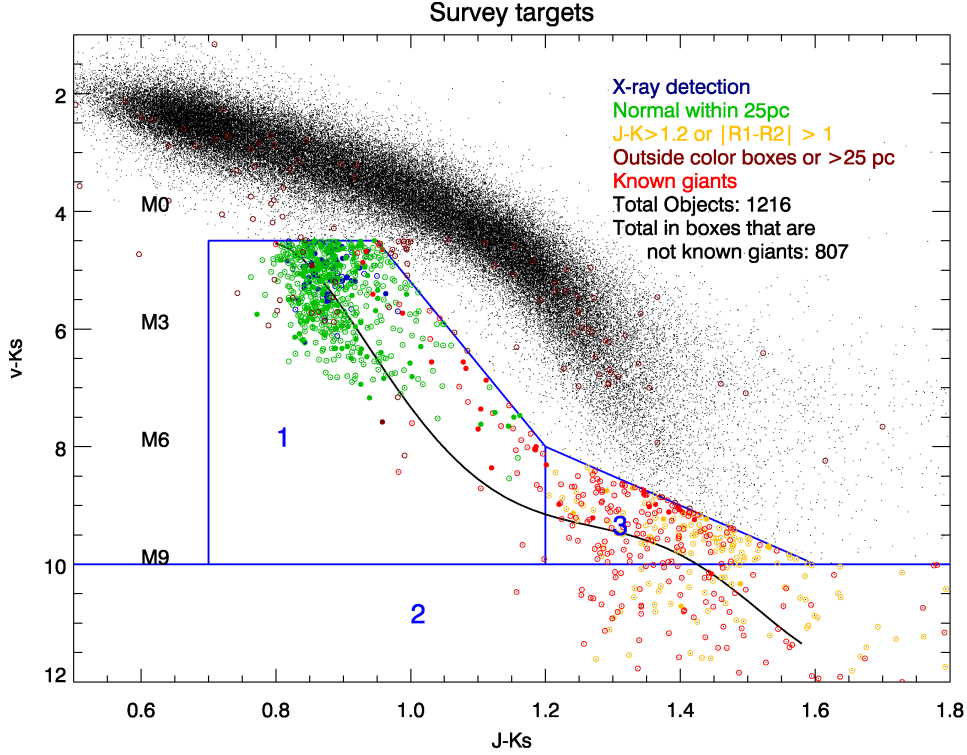


Figure 2. The color-color selection boxes used for the TINYMO search, in $J-K_s$ vs $v-K_s$ space. Curve is a fifth-order fit to the main sequence. Filled circles have been followed up with CCD photometry.

fication account for the open circled points now lying outside the color-color boxes in Figure 2), and d.) previously known objects. At this stage, several proper motion objects (usually companions) were non-exhaustively identified by eye for a total of 1216 objects. Proper motions (which did not form a selection criterion, though they can still be calculated) for these objects range from $0.000''\text{yr}^{-1}$ to $0.444''\text{yr}^{-1}$.

4. Contamination, and how to deal with it

We have thus far assumed every object in the SuperCOSMOS database is a single main-sequence star. This is not accurate, and leads to an enormous contamination problem. In particular, apart from subdwarfs and (theoretically) white dwarfs, contaminants with the colors of main-sequence stars are much brighter; they will have scattered INTO the sample. The most common culprits are giants, especially Mira Ceti variables and AGB stars, whose red colors can look very much like M dwarfs. To this we can also add carbon stars, distant objects reddened by the ISM or a molecular cloud, multiple stars, young stars and (again, theoretically)⁵ AGN.

⁵SIMBAD did identify one X-ray bright object as a possible BL Lac; it is a star at ~ 16 pc

These problems can be solved with additional color criteria, for instance if the SuperCOSMOS R_1 and R_2 magnitudes do not match to within a magnitude, or fewer than 9 of 11 photometric distance relations produced valid results. We have also done literature searches to identify stars, particularly in the The General Catalog of Variable Stars (Samus et al. 2009, in VizieR as b/GCVS) which maintains a list of all known variable stars and can be used to identify Mira variables, Carbon stars, and other semi-regular and irregular giant stars.

Finally, for stars we anticipate following up for parallax (i.e., $\mu < 0.18''\text{yr}^{-1}$ and plate distance within 15 pc – thesis timescales are short), we are obtaining $V_J R_{KC} I_{KC}$ CCD photometry at CTIO, and low-resolution red (6000-9000Å at 10Å resolution) spectra on the CTIO 1.5m telescope with RC Spectrograph, and the Lowell Observatory 1.8m telescope with the DeVeney Spectrograph. Stars that are still within 15 pc by the $V_J R_{KC} I_{KC} JHK_s$ color-distance relations in Henry et al. (2004) AND confirmed to not be giants are being observed for parallax on the Cerro Tololo Inter-american Observatory Parallax Investigation (CTIOPI) (Jao et al. 2005, and subsequent) program.

5. Results

Including star systems like SCR2049-4012 at 9.2 pc and proper motion $0.06''\text{yr}^{-1}$, we have preliminary parallax results for 36 stars in 32 star systems with proper motions less than $0.18''\text{yr}^{-1}$ from the CTIOPI program, consisting of targets from the TINYMO search and other various additions. Sixteen of the parallax targets are within 25 pc and 11 more are between 25 and 50 pc. They are plotted on a color-magnitude diagram in Figure 3, and on the sky with transverse motion vectors in Figure 4.

As can be seen in Figure 3, the vast majority are either multiple, young, or both, lying above (in some cases, well above) the main sequence. Nearly the entire sample spectroscopically observed thus far has H-alpha emission, also suggesting chromospheric activity from either (relative) youth or close duplicity. At least some of this is an observational bias in the sample toward objects with substantial X-ray flux as measured in the ROSAT All-Sky surveys (Voges et al. 1999, 2000); early on it was discovered that nearly every object with an IRAS detection was a giant, and nearly everything with an X-ray detection was a genuine nearby star with a chance of being young. Accordingly, we have focused on obtaining CCD photometry for every X-ray bright system within 25 pc by plate photometry (rather than the usual 15), occasionally the resulting CCD distance estimate is within 15 pc (by $V_J R_{KC} I_{KC}$ CCD photometric distance) and the star is added to the parallax program.

TINYMO (and the CTIOPI parallax program) reveals known members of Beta Pic, TW Hydra and the highly reddening Chameleon I cloud. Of particular interest in Figure 4 are three roughly co-moving points clustered around 12h RA, -35 DEC corresponding to three known TW Hydra members (including 2MASS 1207-3932=TWA 27, Gizis et al. 2007). Three (maybe four) co-moving objects clustered around 21h RA, -35 DEC are new discoveries that may belong to another moving group.

References

- Aumer, M., & Binney, J. J. 2009, MNRAS, 397, 1286. 0905.2512
 Bessel, F. W. 1838, MNRAS, 4, 152

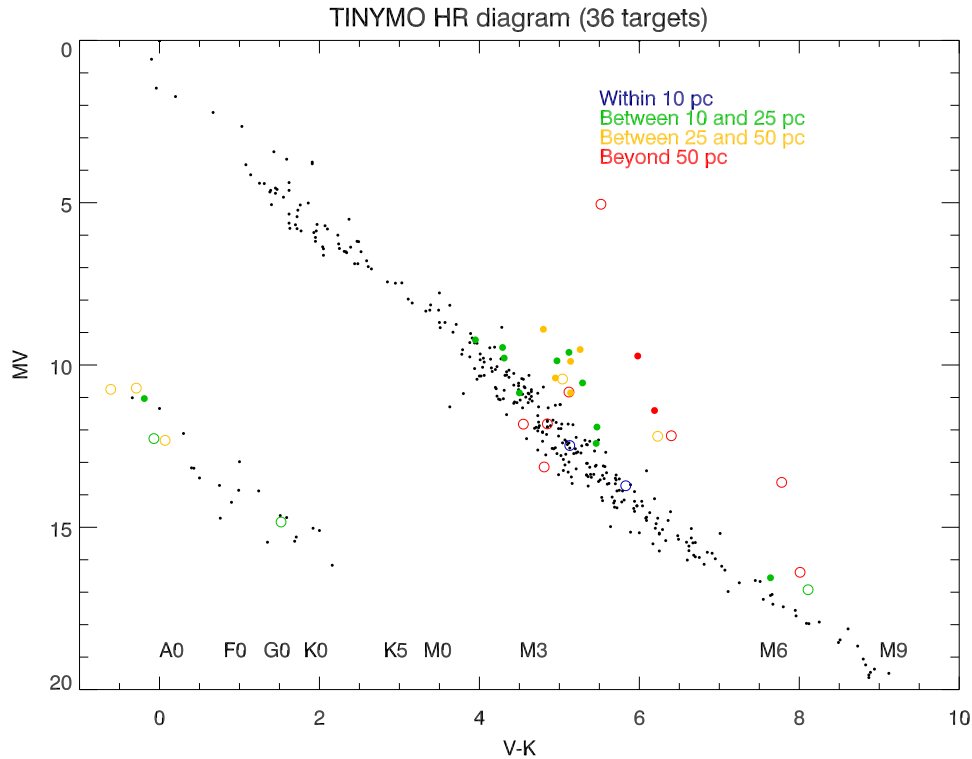


Figure 3. Color-magnitude diagram showing the locations of 36 tiny proper motion objects in 32 systems with preliminary parallaxes from the CTIOPI program. Filled circles are X-ray bright, small points are the RECONS 10 pc sample

- Finch, C. T., Henry, T. J., Subasavage, J. P., Jao, W., & Hambly, N. C. 2007, *AJ*, 133, 2898. [arXiv:astro-ph/0703133](#)
- Giclas, H. L., Burnham, R., Jr., & Thomas, N. G. 1979, *Lowell Observatory Bulletin*, 8, 145
- Gizis, J. E., Jao, W., Subasavage, J. P., & Henry, T. J. 2007, *ApJ*, 669, L45. [0709.1178](#)
- Hambly, N. C., Henry, T. J., Subasavage, J. P., Brown, M. A., & Jao, W. 2004, *AJ*, 128, 437. [arXiv:astro-ph/0404265](#)
- Hambly, N. C., MacGillivray, H. T., Read, M. A., Tritton, S. B., Thomson, E. B., Kelly, B. D., Morgan, D. H., Smith, R. E., Driver, S. P., Williamson, J., Parker, Q. A., Hawkins, M. R. S., Williams, P. M., & Lawrence, A. 2001, *MNRAS*, 326, 1279. [arXiv:astro-ph/0108286](#)
- Henderson, T. 1839, *MNRAS*, 4, 168
- Henry, T. J., Subasavage, J. P., Brown, M. A., Beaulieu, T. D., Jao, W., & Hambly, N. C. 2004, *AJ*, 128, 2460. [arXiv:astro-ph/0408240](#)
- Henry, T. J., Walkowicz, L. M., Barto, T. C., & Golimowski, D. A. 2002, *AJ*, 123, 2002. [arXiv:astro-ph/0112496](#)
- Herschel, W. 1783, *Royal Society of London Philosophical Transactions Series I*, 73, 247
- Jao, W., Henry, T. J., Subasavage, J. P., Brown, M. A., Ianna, P. A., Bartlett, J. L., Costa, E., & Méndez, R. A. 2005, *AJ*, 129, 1954. [arXiv:astro-ph/0502167](#)
- Lépine, S., Rich, R. M., & Shara, M. M. 2005, *ApJ*, 633, L121. [arXiv:astro-ph/0510101](#)
- Lépine, S., & Shara, M. M. 2005, *AJ*, 129, 1483. [arXiv:astro-ph/0412070](#)
- Luyten, W. J. 1979a, *LHS catalogue. A catalogue of stars with proper motions exceeding 0"5 annually*
- 1979b, *NLTT catalogue. Volume.I. +90_to_+30_ Volume.II. +30_to_0_*

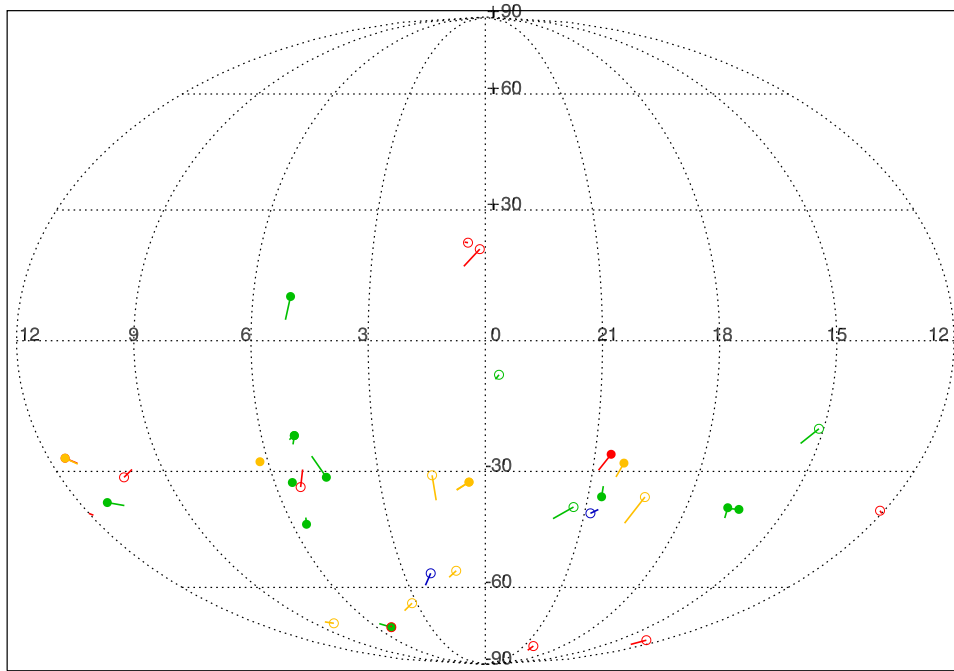


Figure 4. Spatial plot of 36 tiny proper motion objects with parallaxes from the CTIOPI project. Proper motion vectors have been scaled by 180000. Color and fill follow Figure 3.

- 1988, in *Mapping the Sky: Past Heritage and Future Directions*, edited by S. Debarbat, vol. 133 of IAU Symposium, 301
- Perryman, M. A. C., Lindegren, L., Kovalevsky, J., Hoeg, E., Bastian, U., Bernacca, P. L., Cr    , M., Donati, F., Grenon, M., van Leeuwen, F., van der Marel, H., Mignard, F., Murray, C. A., Le Poole, R. S., Schrijver, H., Turon, C., Arenou, F., Froeschl  , M., & Petersen, C. S. 1997, *A&A*, 323, L49
- Riedel, A. R., Subasavage, J. P., Finch, C. T., Jao, W., Henry, T. J., Winters, J. G., Brown, M. A., Ianna, P. A., Costa, E., & Mendez, R. A. 2010, *AJ*, 140, 897. [1008.0648](#)
- Samus, N. N., Durlevich, O. V., & et al. 2009, *VizieR Online Data Catalog*, 1, 2025
- Subasavage, J. P., Henry, T. J., Hambly, N. C., Brown, M. A., & Jao, W. 2005, *AJ*, 129, 413. [arXiv:astro-ph/0409505](#)
- Voges, W., Aschenbach, B., Boller, T., Br    niger, H., Briel, U., Burkert, W., Dennerl, K., Englhauser, J., Gruber, R., Haberl, F., Hartner, G., Hasinger, G., K    rster, M., Pfeffermann, E., Pietsch, W., Predehl, P., Rosso, C., Schmitt, J. H. M. M., Tr    mper, J., & Zimmermann, H. U. 1999, *A&A*, 349, 389. [arXiv:astro-ph/9909315](#)
- Voges, W., Aschenbach, B., Boller, T., Brauningner, H., Briel, U., Burkert, W., Dennerl, K., Englhauser, J., Gruber, R., Haberl, F., Hartner, G., Hasinger, G., Pfeffermann, E., Pietsch, W., Predehl, P., Schmitt, J., Trumper, J., & Zimmermann, U. 2000, *iaucirc*, 7432, 1